Faculty of Manufacturing Engineering

SHAPE PRESERVING IN AERODYNAMIC PRODUCT PROFILES USING GEOMETRIC DESIGN MODELLING

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DECLARATION

I declared that this thesis entitled “Shape Preserving in Aerodynamic Product Profiles Using Geometric Design Modelling” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………….

Name : NORILANI BINTI MD.NOR HAYATI

Date : ……………………………………………….

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation is sufficient in terms of scope and quality as partial fulfillment of Master of Manufacturing Engineering (Industrial Engineering).

Signature	: ……………………………………………….
Supervisor Name	: TS. DR. SAIFUDIN HAFIZ BIN YAHAYA
Date	: ……………………………………………….

DEDICATION

To my beloved parents, family, supervisor, and to all amazing people I've met along this journey.

Thank you so much for the endless support.

ABSTRACT

Shinkansen bullet train was inspired by Kingfisher beak which the nose shape design of the bullet train is streamlined, and influenced the aerodynamic consumption. Long nose shape design lead to high production cost, material usage and longer building time. Therefore, the high-profile curve design which Bezier curve was applied to improve the nose shape design of Shinkansen bullet train while preserving the other specifications of Shinkansen bullet train. C-shaped transition curves was chosen to solve this problem due to its extreme curvature that able to exhibit smooth curvature. C-shaped transition curve was used to construct an improved design by applying it at the nose shape of Shinkansen. SolidWorks SimulationXpress and ANSYS Fluid Flow (FLUENT) packages are the software used to conduct linear static analysis and dynamic analysis respectively. The improved design was compared to the existing design of Shinkansen in the analysis. As a result, design with high-profile curve application shows better result in terms of Von Mises stress, displacement, velocity, and pressure. These results are been validated by using coefficient of variation and design efficiency to identify its reliability of design. Based on the linear static analysis, Von Mises stress and displacement results showed the improved design had less value compared to the existing design. This also depicted that the improved design took a longer time to undergo the failure mode. Meanwhile, in dynamic analysis, the velocity and pressure were the output parameters. The results were justified by colour indicators. Thus, the results also fulfilled the Bernoulli principle. Undoubtedly, improved design shows better result compared to existing design.

PENGEKALAN BENTUK DALAM PROFIL PRODUK AERODINAMIK MENGGUNAKAN PEMODELAN REKA BENTUK GEOMETRI

ABSTRAK

Kereta api laju Shinkansen yang diinspirasikan daripada paruh Burung Raja Udang yang rekabentuk hidungnya diselaraskan, dan mempengaruhi kesan aerodinamik. Rekabentuk bentuk hidung yang panjang membawa kepada kos pengeluaran yang tinggi, penggunaan bahan dan masa pembinaan yang lebih lama. Oleh itu, rekabentuk lengkung berprofil tinggi yang mana lengkung Bezier diaplikasikan untuk menambahbaik rekabentuk hidung kereta api laju Shinkansen sambil mengekalkan spesifikasi Shinkansen yang lain. Lengkung peralihan berbentuk C dipilih untuk menyelesaikan masalah ini kerana kelengkungannya yang ekstrem yang mampu menghasilkan kelengkungan halus. Lengkung peralihan berbentuk C digunakan untuk membina rekabentuk yang diubahsuai dengan mengaplikaskannya pada bentuk hidung Shinkansen. Pakej 'SolidWorks SimulationXpress' dan 'ANSYS Fluid Flow (FLUENT)' ialah perisian yang digunakan untuk melaksanakan analisa statik linear dan analisa dinamik. Rekabentuk yang diubahsuai ini dibandingkan dengan rekabentuk asal Shinkansen untuk tujuan analisa. Hasilnya, rekabentuk dengan aplikasi lengkung berprofil tinggi menunjukkan hasil yang lebih baik dari segi tekanan Von Mises, anjakan, halaju, dan tekanan. Hasil ini disahkan dengan menggunakan pekali variasi dan keberkesanan rekabentuk untuk mengenal pasti kebolehpercayaan rekabentuknya. Berdasarkan analisa statik linier, hasil tekanan Von Mises dan anjakan menunjukkan rekabentuk yang diubahsuai mempunyai nilai yang lebih rendah berbanding dengan rekabentuk yang sedia ada. Ini juga menggambarkan bahawa rekabentuk yang diubahsuai memerlukan masa yang lebih lama untuk mengalami mod kegagalan. Sementara itu, dalam analisa dinamik, halaju dan tekanan adalah parameter output. Hasil ini dijustifikasikan oleh petunjuk warna. Hasil ini juga memenuhi prinsip 'Bernoulli'. Tidak boleh dinafikan, rekabentuk yang dibubahsuai menunjukkan hasil yang lebih baik berbanding dengan rekabentuk yang sedia ada.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATION

1. Yahaya, S.H., Norilani, M.N.H., Salleh, M.S., and Warikh, A.R.M., 2020 (in press). Shape Preserving in Aerodynamic Product Profiles Using Geometric Modelling. *Proceeding of Innovative Research and Industrial Dialogue 2020*.

CHAPTER 1

INTRODUCTION

This chapter will discuss about the research background of this study followed by problem statement. Then, this chapter will proceed with the significance of this research, objectives of the study, and scope of the study. Finally, the whole content for this chapter will summarized in summary subtopic.

1.1 Research Background

Transportation has been one of the important aspects in order to move a persons or goods from place to place. Some of the modes of transport are air, land, (rail and road), water, cable, pipeline and space which has a transport infrastructure such as airways, railways, roadways, waterways, and pipelines respectively. The international growth of transport links an increase in tourism providers professionalism and rapidly evolving technological progress in both transportation capability and management were followed by a shift in consumer behaviour marked by an increase in longing for distant places (Egger, 2014).

Transportation requires a good design or shape in order to run smoothly even with its high speed. Airflow is one of the constraints. Therefore, aerodynamic design of transportation is very important in order to travel with less resistance and safely. In this research, train is taken as the subject. Trains need to have a good aerodynamic and streamlined body. This is because it works near to the ground and it have much greater length-to-diameter ratio compared to airplane, car and boat. It is also subjected to crosswinds as it travels to tunnel, underground, and in even in between buildings. It is also travel at many speeds which are low and high according to the situation. In addition to that, most of the trains are operating at the route where it needs to go through numerous tunnels (Mueller & DeLaurier, 2003).

Aerodynamics of a train are mainly from its nose and tail design. Curve of both nose and tail will affect most of the aspects for train, especially speed, noise, and pressure. Streamlined trains at speeds of around 250 up to 300 km/h, 75% to 80% of the total resistance is caused by external aerodynamic drag, while others are from other various factors such as skin friction, nose and tail pressure drag, interference drag, and also by pantograph and equipment drag (Mueller & DeLaurier, 2003). Aerodynamic shape optimization of any transport will produce good result as it matches the transition curves. This method implemented produce a good airfoil but will occur some difficulties near the high lift coefficient, which were the attribute to the airfoil parameterization in the leading-edge region (Gamboa & Silvestre, 2013).

The transition curve defines a curve where a gradual transition from the straight to the circular curve is accomplished, with the curvature changes from zero to finite (Yahaya *et al*., 2008). In this research, Shinkansen bullet train is chosen as a profile as it has long and streamline shape design. The nose shape of the bullet train is improved by applying transition curve.

1.2 Problem Statement

Shinkansen can accelerate up to 320 km/h due to the great stability and powerful mechanism used. The stability is caused by design of the entire Shinkansen which is contributed mainly by the head and tail of the train itself. Both of the head and tail of the train must in the perfect design to make it aerodynamically good. Aerodynamic of the train is mostly based on the streamlined shape of the nose. This will have a certain curve depending on the model of the train, to make it accelerate with high speed and stable.

One of the criteria of high-speed train that really effect the speed is the design shape of nose of the train (Mueller et. al., 2003). Nose length and design of nose of train can vary in every model and each of that will give an impact on the performance of the train. Nose length can effect on the train surface pressure concentration on the train head and train tail (Niu et. al., 2018). However, huge production cost in the aerodynamic optimization will be required especially in shape optimization of high-speed train (Shuanbao et. al., 2014). This is because more raw material will be needed in order to complete the long-nose shape design of the train therefore the high production cost will be affected. Furthermore, longer time of train construction is spent. Therefore, there will be so many wastes in building one unit of bullet train, Shinkansen.

To get a perfect curvature, C-shaped transition curve is chosen as the line of curvature due to its high-profile design. For a high-speed train, aerodynamic features are important to achieving high speed and low pressure. C-shaped transition curve is suitable for producing a high aerodynamic bullet train, as it can withstand undesirable extreme curvature and exhibit smooth curvature variation. By applying the design of C-shaped transition curve, the projected high-profile curve definition can be achieved.

1.3 Significance of Study

On this research, Shinkansen Bullet Train are focused only at the nose shape design where it is to be redesigned by applying a high-profile curve definition. The C-shaped transition curve is chosen to be the high-profile curve. The rest of the dimensions or parameters of the train are remained as the existing Shinkansen model.

After the design is improved with the high-profile curve, it is been simulated with three analyses, which are linear static analysis, fatigue analysis, and dynamic analysis. These analyses give result such as failure conditions, pressure at certain point, and its fatigue. Linear static analysis will give a result in deformation and decrement in Von Mises Stress. Fatigue analysis is the prediction of fatigue can be obtained by applying linear interpolation based on the safety factor obtained from the linear static analysis. Both of this analysis made by using SolidWorks SimulationXpress. Dynamic analysis is made by using ANSYS Fluid Flow (FLUENT) package to get the result of failure and pressure with input velocity is included. These are the analysis that is to be conducted and validate.

For validation, both of existing model and improved model are compared based on Design Efficiency (DE) and Coefficient of Variation (CV). DE is calculated by using the output parameter from linear static analysis, while CV is calculated by using the output parameter from dynamic analysis.

1.4 Objectives of the Study

The objectives of this research study are listed as follows:

i. To study the concept of high-profile curve definition.
ii. To design the nose shape of Shinkansen.
iii. To apply the Bezier Curve in the design as improved design.
iv. To analyse both existing and improved designs using linear static analysis and dynamic analysis.
v. To validate both existing and improved models using Design of Efficiency (DE) and Coefficient of Variation (CV).

1.5 Scope of the Study

Curve design is one of the important aspects in order to achieve the greatest performance. The research starts with the introduction where the background research, objectives, problem statements, research significant, and scopes are discussed. The scope of this research focuses only on the shape design of train nose. The trains that will be focused is high-speed train, which Shinkansen E5. This is because this model has among the longest nose compared to other models of high-speed train.

The existing model of Shinkansen E5 are constructed in SolidWorks software to get the profile design. This drawing will be compared with the improved design, where the nose design of the train will be changed. The improved design will be made based on the clothoid template and C-shaped transition curve. Both designs are made by 2D sketching and 3D modeling.

Analysis for both models will be conducted to determine the ability and limit condition for both models. Firstly, linear static analysis is conducted to identify the capability of design with loading in static structure. Next, fatigue analysis is carried out to estimate fatigue life of the design or a product. Both of this analysis is conducted by using SolidWorks SimulationXpress software and SolidWorks SimulationXpress software respectively. Then, the analysis of dynamic for both designs are made by ANSYS Fluid Flow (FLUENT) package. This analysis is to determine the maximum speed and velocity of the models. Finally, the validation is been made by calculate the design of efficiency. This calculation can determine either the model and applied material are suitable for the manufacturing.

1.6 Report Organization

This study started with Chapter 1 which is introduction of the background for this research, problem statement, significance, objectives, and scopes of the study. The background of the research study will discuss about the growth of rail transportation impact towards world. The aerodynamic of train will be explained followed by the curve design application. Problem statement explains how current nose shape design gives an impact towards economy. This chapter followed by scope of this research, where it explains about the limitation of this research. Finally, this chapter ends with the report organization where it explains the details about every chapter in this research.

Chapter 2, discuss the development of rail transportation followed by development of high-speed train in world. Next, transition curve design is described. In this subchapter, 5 transition curve template which are C-shaped, S-shaped, J-shaped, straight line to straight line, and circle to circle. 3 types of curves will be discussed which are Cubic Bezier Curves, Clothoid Segment Curves, and Pythagorean Hodograph (PH) Quantic Curves. This chapter is continued by summary of previous study about analyses that is going to be carried out. Finally, it ends with summary for this chapter.

Chapter 3 explains the methodology and process flow of this research. Method of study and method of analysis are explained, which method of study involve Shinkansen's design as existing model and the design for application of Bezier Curve design as improved model. Each step taken in order to get the drawing will be explained in this chapter. Next, method of analysis is elaborated. This covers how the analyses will be conducted. The analysis explained here will be linear static analysis and dynamic analysis. This chapter ends with preliminary result, where the plan or method of analysis are made.

Chapter 4 discuss about result obtained from linear static analysis and fatigue analysis. This is done by using SolidWorks SimulationXpress. The parameters output for this analysis is stress and displacement for both existing and improvement designs. There will be some setting need to be done such as boundary conditions and material selection. Based on the output, fatigue analysis will be done by calculating its safety factor. As for validation for linear static analysis, design efficiency (DE) is calculated.

Chapter 5 explains about the analysis conduct by using ANSYS FLUENT to identify the result of dynamic analysis. Few steps will be taken such as boundary settings and velocity of air settings. The output parameters will be velocity and pressure exerted by the Shinkansen. As for validation, the result on both designs for both parameters will identify standard deviation and the mean. Coefficient of variations (CV) is calculated. The lower CV means high quality and better stability.

Chapter 6 conclude the whole project with conclusion, recommendations, and sustainability. Each objective is revised and briefly recap in order to check its achievement. The recommendation will discuss about comment for future study. Sustainability of the research will be discussed in terms of this project.

CHAPTER 2

LITERATURE REVIEW

This chapter gives a review about previous research, studies, and data that are related to this research title which are nose shape design of bullet train. It starts with the development of rail transport where history of trains is review in this subchapter. Next, all of the high-speed train are discussed, followed by the Shinkansen development. Then, few curve templates with are discussed continued by the explanation about Cubic Bezier Curve, Clothoid Segment Curves with its application. In addition, some method of analysis will be discussed. This chapter end with summary of the whole content of this literature review.

2.1 Development of Rail Transport

Rail transport, or generally referred to as train transport, is meant to move people and goods on wheeled vehicles traveling on rails that consists of steel rails, installed on ties set in ballast, rolling stock that usually fitted with metal wheels. Up to year 2018, the world railway system length is 1.4 Million route-km, which most of the railway is at European country. However, there are some of the country that still does not have any railway system.